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14. ABSTRACT

Dr. Eric Kunze and Dr. Pascale Lelong numerically explored an alternative solution to Baines' 1982 internal tide generation theory for arbitrary 1-D topography h(x). The method and the results are described. Drs. Kunze and Lelong's subsequent contributions to the literature of internal tide generations are referenced.

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Final Performance Report

Internal Tide Generation by Steep Topography

Office of Naval Research Grant N00014-04-1-0212
Performance Period: 1 December 2003 – 30 September 2007

Eric Kunze and Thomas Sanford, Principal Investigators

The purpose of this proposal was to support Drs. Eric Kunze, Applied Physics Laboratory, University of Washington (now at U of Victoria) and Pascale Lelong (via a subcontract to Northwest Research Associates, Seattle, Washington) to numerically explore an alternative solution method to Baines' (1982) internal tide generation theory for arbitrary 1-D topography $h(x)$. The solution method uses characteristic coordinates along which signals of frequency ω propagate,

$X_{\pm\pm} = \pm x \pm sz$, where the inverse ray path slope $s = N/\sqrt{\omega^2 - f^2}$, to formulate a forced differential equation for the along-ray velocities

$$\frac{\partial U_{\pm}}{\partial X_{\pm}} = \pm \frac{U_0 h_0 z}{4} \frac{\partial^2}{\partial x^2}\left(\frac{1}{h}\right),$$

from which one obtains the baroclinic along-ray velocity by integrating along a ray path

$$U_{\pm} = \pm \frac{U_0 h_0}{4} \int_{X_{\pm}} (z + \frac{h}{2}) \frac{\partial^2}{\partial x^2}\left(\frac{1}{h}\right) dX_{\pm}.$$

This involves integrating 4 forced equations for the along-ray velocities from boundaries to each point in the domain (Fig. 1).

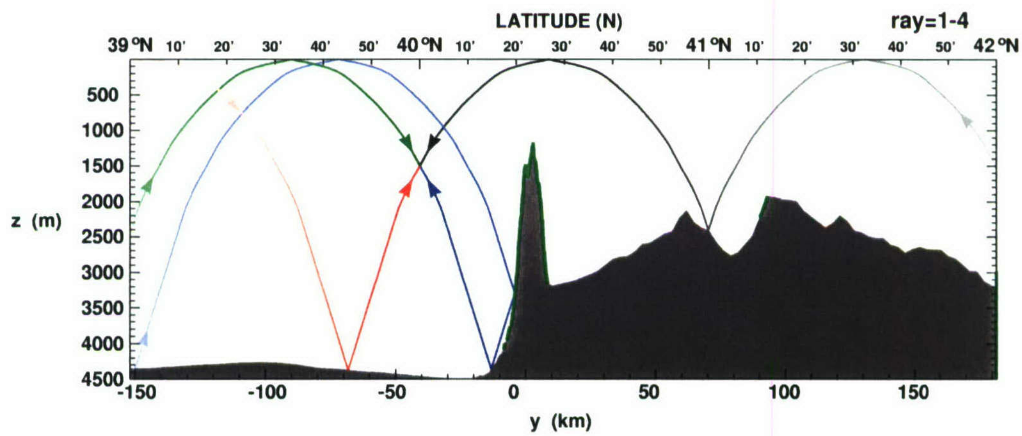

Figure 1: Illustration of solution method for a section across Mendocino Escarpment. Supercritical topography is indicated in green. Each point is influenced by information travelling along 4 rays that are assumed to enter the domain with zero along-ray velocities ($U_{\pm} = 0$). The complete solution is obtained by integrating along the rays, then summing the 4 solutions.

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Work prior to proposal submission appeared to encouragingly produce the observed energy structure for Mendocino Escarpment bathymetry (Althaus *et al.* 2003) that suggested that the approach would bear fruit (Fig. 2).

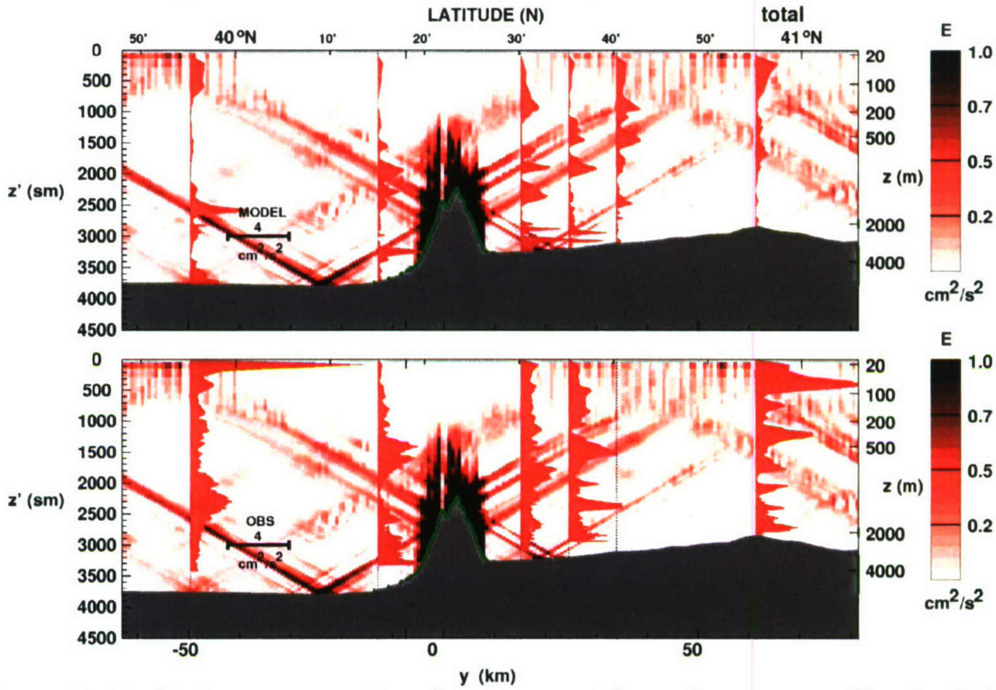

Figure 2: Preliminary comparison between semidiurnal energy profiles (red) from the new solution method (upper panel) and observations across Mendocino Escarpment (lower panel). The background red shading shows the model solution everywhere in both panels.

Closer examination of the solutions for idealized bathymetry (ridges, steps) revealed a physical energy-flux behavior. Comparison with small-amplitude theory (Bell 1975) and the knife-edge solution of St. Laurent *et al.* (2003) also revealed discrepancies. Consultation with other experts in internal tide generation (Theo Gerkema, Leo Maas, Chris Garrett) raised suspicions that the problem's boundary conditions are ill-conditioned and partition of the forcing between the 4 rays arriving at each point is ambiguous.

To make a contribution to internal tide generation, Eric Kunze has co-authored a recent review of theory (Garrett and Kunze 2007). Drs. Kunze and Lelong are preparing a short manuscript (Kunze, E, and P. Lelong, Internal Tide Generation by Surface-Tide/Eddy Interactions) describing generation of internal tides by the interaction of surface tidal currents with baroclinic geostrophic eddies. When the aspect ratio of the eddy field *H/L* matches the aspect ratio of internal tides (λ_h/λ_z), resonant interaction will transfer energy from the barotropic to baroclinic tide. This mechanism appears not to have been previously recognized. Theoretical development is complete and numerical simulations to test the theory have demonstrated the generation of internal waves when resonant conditions are met. This research will be presented at the upcoming Ocean Sciences meeting during March 2008 and at a symposium to honor Chris Garrett on his 65th birthday in July 2008 and will be submitted to a special issue devoted to the symposium in the peer-reviewed journal *Atmosphere-Ocean*.

In addition, Eric Kunze is working on a short manuscript describing the parametric subharmonic instability (PSI, McComas and Bretherton 1977) transfer of energy from the barotropic semidiurnal tide to baroclinic waves of half the frequency. There have been numerous publications recently describing the PSI transfer from low-mode internal tides to high-wavenumber near inertial waves (Nagasawa *et al.* 2002; Hibiya *et al.* 2002; MacKinnon and Winters 2005; Furichi *et al.* 2005; Gerkema *et al.* 2006; Alford *et al.* 2007; Young and Tsang 2007) but the only one previous examination of this mechanism acting on the barotropic tide (Foda and Hill 1998) was incomplete. Kunze will put this work in the context of recent internal tide research and estimate the global transfer rate from the barotropic tide.

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